

ASTRA 3B HORN ANTENNA DESIGN

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ABSTRACT

The ASTRA 3B satellite includes 60 Ku-band state-of-the-art transponders and 4 Ka-band transponders. The spacecraft have been designed for the distribution of both direct-to-home (DTH) broadcast services and two-way broadband services across Europe. After Astra 2B and Astra 1M, Astra 3B is the third Astra satellite to be built by ASTRIUM.

Two different horn antennas, for Ku- and Ka-bands, were designed with very stringent requirements as it is usually required for space applications. For the horns the cross-polar levels should be below -45 dB, and the return loss below -30dB for all frequency bands.

Normally the horn aperture is fixed by the required illumination of the reflector edges, so it is difficult to reduce the aperture size of a horn antenna. Nevertheless, thanks to the design technique used, the relation between the output aperture and the total horn length for the Ka-band was approximately 0.56 and for the Ku-band was something like 0.76. This means that the lengths of the horn antennas are 1.8 and 1.32 times the respective apertures.

Furthermore, the taper and the phase center movement inside the respective bandwidths could be controlled and limited to certain limits during the optimization procedure, obtaining a very efficient configuration when they were combined with the reflectors.

The horn antennas were based on the combination of horizontal and vertical corrugations and they were designed by the Antenna group of the Public University of Navarra.

1. INTRODUCTION

Telecommunication satellite horn antennas require nowadays more and more stringent requirements based mainly in the increased bandwidth necessary to accommodate more transponders to increase the capacity of the new satellite services. In this aspect horn antennas play a key role in the development of wider bandwidth services on board satellites because they are usually the reason that limits bandwidth in a satellite antenna.

Our research group had designed a corrugated horn antenna for Hispasat 1C and 1D satellites in the late 90's [1]. Such horn antenna was based in Gaussian profiled techniques that reduced horn length and increased its performance. In 2002 we discovered a way

to reduce dramatically the length of a corrugated horn antenna maintaining its optimum performance [2], a horn antenna that combines horizontal corrugations for the throat region and vertical corrugations for the flare region.



Figure 1.- Tx/Rx Ka-horn model for ASTRA 3B satellite

The development of this technology [3] has travelled in parallel with the development of efficient software tools suitable for simulation and optimization of passive microwave systems and components, including antennas. We are especially comfortable with the mode-matching technique based software called μ Wave WizardTM and in fact we use such software to analyze and optimize the horn antennas that combine horizontal and vertical corrugations with very nice results.

2. CHOKED-GAUSSIAN HORN ANTENNAS

Choked-Gaussian horn antennas were discovered by means of the research activity of the Antenna Group at the Public University of Navarra in Pamplona, Spain. The possibilities that this kind of horns could offer were from the first moment very interesting because the radiation pattern performances were very promising and the horn was very compact (compactness referred to size). This new type of corrugated horn antennas was easier to manufacture than normal corrugated profiles

[2].

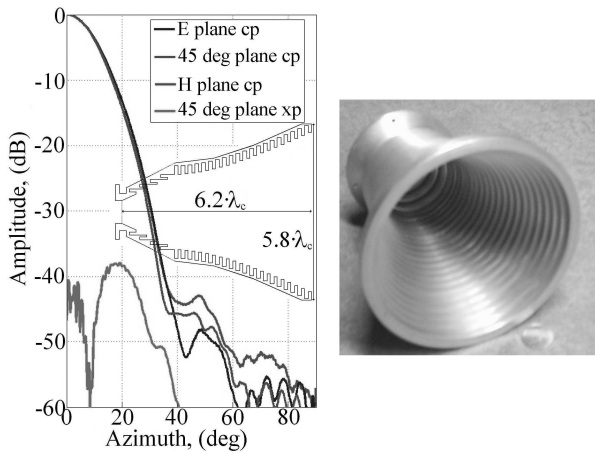


Figure 2.- First corrugated horn antenna that combines horizontal and vertical corrugations designed and manufactured [2].

In fact, this kind of horn antennas is so simple that its working principle is the combination of two different technologies of horn antennas. One of these technologies is used for the throat and consists on horizontal corrugations, this leads to a shorter profile generating a Gaussian-like field distribution at its aperture. The second technology is used for the flare region and consists in vertical corrugations to improve the far field radiation pattern.

2.1. Horn antenna size

One of the principal advantages of this new technology of corrugated horn antennas is their size. In fact their length is at least half the length of normal conical corrugated horn antennas, maintaining relatively wide bandwidth behaviour (20%). The output diameter remains the same as usual for horn antennas and must be selected depending upon the side-lobe level required. Usually Gaussian profiles are selected for the second vertical corrugated part.

In figure 3, there is a comparison between the normalized length and aperture of conical corrugated conventional horn antennas of the same directivity counterpart using the Choked-Gaussian technology. It is important to remark that the conventional conical corrugated horn antenna, used in this comparison, has the side-lobes between 20-25 dB, whilst the Choked-Gaussian is always below 30 dB.

Nowadays, other profiles result in much shorter designs, but, at least at the moment, this is one of the best that combines small size with wide bandwidth, [3,4,5].

Regarding the total size of the profile, in figure 3, the approximate pessimistic values are given for 20% bandwidth. If bandwidth requirements are narrower, a shorter profile than the given in figure 3 can be designed.

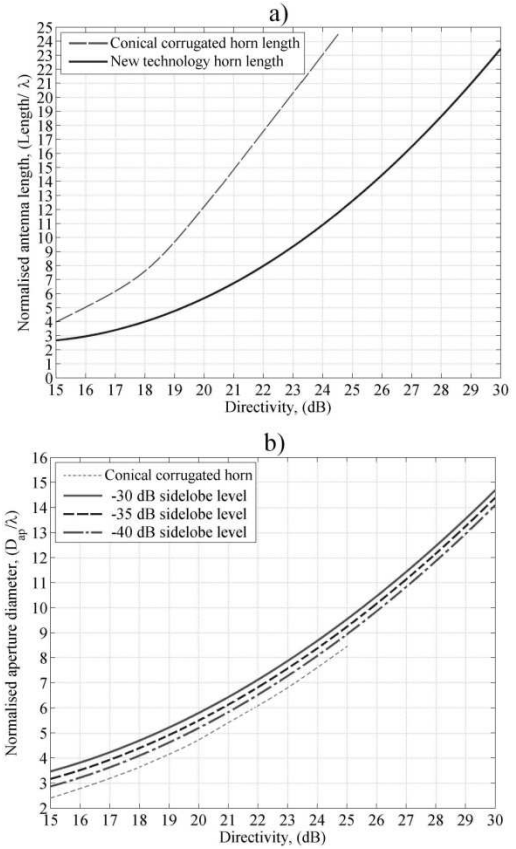


Figure 3.- Size properties of horn antenna that combines horizontal and vertical corrugations.

a) Horn antenna length versus directivity.

b) Horn antenna output diameter versus directivity.

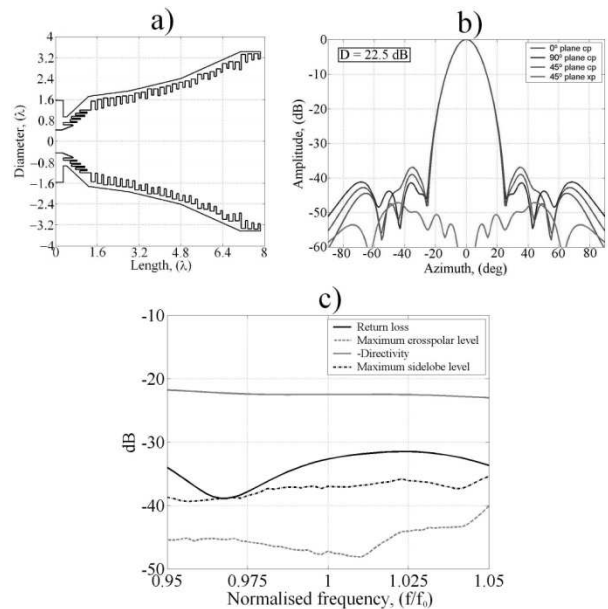


Figure 4.- 22.5 dB gain compact corrugated horn antenna

a) Horn antenna profile.

b) Radiation pattern at f_0 .

c) Radiation properties

In figure 4, an example of this technology corrugated

horn antennas is presented. The bandwidth is around 10% ensuring a return loss below -30 dB, a crosspolar level below -35 dB and a sidelobe level around -40 dB in a ridiculous 8λ length for 22.5 dB gain.

2.2. Efficiency, spillover and side-lobes

Regarding the efficiency, it is important to distinguish between the different definitions normally referred as efficiency and always related with antennas.

The first definition of efficiency, the related with transmission, is the one relating the directivity and gain of an antenna, representing the losses of an antenna system.

A second use of efficiency, it is linked with the capability to define a uniform field distribution, amplitude and phase, at the aperture of a horn antenna or a reflector system, related with reception. Sometimes, this efficiency is also called as *aperture efficiency*, and normally is referred to the physical area of the aperture.

For instance, it is well known that a uniform distribution covering all the radiating aperture of an antenna will define an aperture efficiency of 100% but, on the other hand, the radiation will have an important level of side-lobes around -13 dB, which will reduce the total power launched in forward direction, in other words, the spill-over would be relevant.

In this sense, the nice performance horn antenna, i.e., low side-lobes, low cross-polarization, etc., normally do not present efficiencies better than 50-60%.

Other quite common example is a complete reflector system, where these two concepts are more or less combined, arising a combined concept of efficiency, which takes into account the losses of the prime feeder (spill-over: radiated power which do not achieve the reflector surface) and the uniformity of the aperture fields.

In this configuration, since only the central part of the feed diagram is used to illuminate the reflector, the side-lobes of the feeder are normally neglected. Nevertheless, in the overall summation of the loss power, the energy spread out through the side-lobes will reduce the maximum achievable efficiency.

2.3. Choked-Gaussian horn as feeder

The low side-lobe level is a clear advantage of this kind of corrugated horn antennas. Nowadays, many applications require very low side-lobes to fulfil all the specifications.

Also, acting as a feeder of a reflector in a satellite environment, to have the side-lobe level as low as possible is important to avoid interference with other systems. In these cases, the side-lobe radiation contributes, directly, to the spill-over radiation.

The spill-over radiation, η_s , is the amount of unwanted power that an antenna radiates outside the region of

interest [3, 4]. A high spill-over radiation reduces the signal to noise ratio quite dramatically.

Other important parameter to completely define these systems, it is to determine the illumination at the edges of the reflector, in order to illuminate it as uniformly as possible. The way to evaluate it is through the illumination efficiency, η_i .

The illumination efficiency could also be calculated as the ratio of the directivity of the horn, in that particular angular region, with the directivity of a uniformly illuminated antenna of the same aperture size.

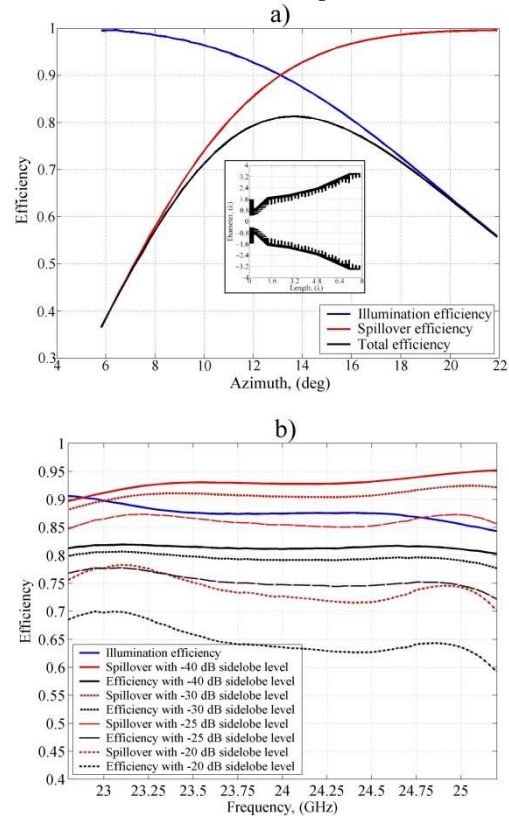


Figure 5.- Efficiencies for the 22.5 dB gain corrugated horn antenna.

a) Illumination, spillover and their product at f_0 depending on azimuth angle for -40 dB sidelobe level

b) Illumination, spillover and their product at 14 deg illumination angle depending on frequency for -40, -30, -25 and -20 dB sidelobe level.

There are other factors to determine the global efficiency, as the cross-polar definition at the aperture plane, the phase planarity, etc., trying to evaluate the amount of useful power delivered at the aperture plane in relation with the delivered to the feeder, as the input of the antenna system, the overall efficiency.

This efficiency of the total system is obtained multiplying all the defined partial efficiencies, being the two more determinant the spill-over and the illumination efficiencies. For corrugated horn antennas, the cross-polarization is always quite well defined at the

main beam, and the phase centre is quite stable in the frequency band, so no big changes can be expected from these two parameters.

Usually, the maximum of the global efficiency happens when the product of the two main efficiencies is maximised, see figure 5a. This maximum occurs for an angle where the edge illumination of the reflector is around -10 to -11 dB.

In figure 5b we have calculated these efficiencies for the radiation pattern of figure 4 where the side-lobe level is below -40 dB. We have also altered that radiation pattern increasing exactly the side-lobe level to calculate the efficiencies in another three cases; -30 dB, -25 dB and -20 dB, leaving unaltered the main beam.

The result is that for an illumination angle of 14 degrees, the illumination efficiency is exactly the same for the four cases, (as there has been no change of the main beam), but the spillover efficiency changes as it was assumed, (see figure 5b). This change produces a change in the overall efficiency of the horn antenna. In fact the total efficiency, when the side-lobe level is around -20 dB is a 10 % lower than when it were below -30 or -40 dB, where little variation has been detected.

3. ASTRA 3B HORN ANTENNA DESIGN

The ASTRA 3B satellite uses two different systems in Ku- and Ka- bands. The horn antennas that have been designed are the Rx of the Ku-band (14-18 GHz) and the Tx/Rx Ka-band (21.3-29.7 GHz).

The rest of requirements are: a simulated cross-polar maximum level below -45 dB and a co-polar radiation pattern with as constant taper along the frequency band as possible to assure the footprint of the satellite over the earth to be frequency independent. As important as the pattern stability is the phase centre stability through all the frequency bandwidth.

3.1. Ku-band horn antenna design

In this case, there are two different receiving bands, defining a total bandwidth of 25%.

The selected horn antenna profile is a combination of horizontal and vertical corrugations, the so called, Choked-Gaussian horn antennas, which allow the designer to fulfil the stability requirements.

During the optimization process of the final profile, the objective was defined trying to keep constant over the entire frequency band: the taper (directivity and far field pattern level at 25.5 degrees) and the phase centre.

In figure 6, the profile (a), the return loss (b), the maximum cross-polarization (c), the directivity (d), the phase centre (e) and the taper illumination at 25.5 degrees (f) are shown.

3.2. Ka-band horn antenna design

In this case, there are two different receiving bands and

a transmitting band at the lower part of the frequency band, defining a total bandwidth of 33%.

The selected horn antenna profile is as well a combination of horizontal and vertical corrugations, the so called, Choked-Gaussian horn antennas, which allow the designer to fulfil the stability requirements.

During the optimization process of the final profile, the objective was defined trying to keep constant over the entire frequency band: the taper (directivity and far field pattern level at 19 degrees) and the phase centre.

In figure 7, the profile (a), the return loss (b), the maximum cross-polarization (c), the directivity (d), the phase centre (e) and the taper illumination at 25.5 degrees (f) are shown.

In figure 8, some measured far field patterns of this Ka-band horn antenna are shown.

4. COMENTS ABOUT THE RESULTS

As it could be seen from the figures 6 and 7, the final prototypes are really short. As it has been explained, the aperture is directly related to the required directivity, so no big differences would be found there with respect with the classical techniques. However, the length of the horn designs have been strongly reduced thanks to the combination of two well known techniques: Choked horn antenna (opening from the input mono-mode waveguide radius to an aperture where a Gaussian-like field distribution could be properly defined) and the corrugated profiled horn antenna to purify the Gaussianity of the inner field distribution to obtain the desired performance of the final radiation pattern.

Regarding the cross-polar plots, figure 6c and 7c, two curves are shown: the blue curve shows the maximum value of the cross-polarization at any angle (it could be out of the angles of interest); and the red curve shows the maximum level of cross-polarization in the angles illuminating the reflector.

It is important to mention the good performance of the two designs maintaining the illumination taper and phase centre in the entire frequency band. This feature is particularly important knowing that the reflectors illuminated by the horns, would be shaped in order to cover efficiently the desired pattern over the earth surface.

5. CONCLUSIONS

In this paper the two different horn antenna designs performed by the Antenna Group of the Public University of Navarra for the telecommunication satellite ASTRA 3B have been presented.

The horn antenna designs fulfill the electromagnetic requirements and results to be very compact and light, quite valuable features for boarding the antenna on a satellite.

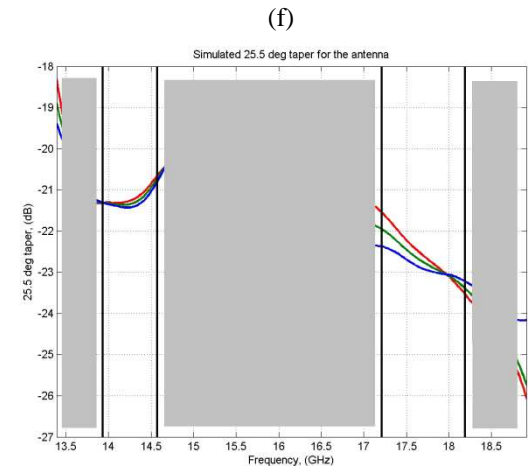
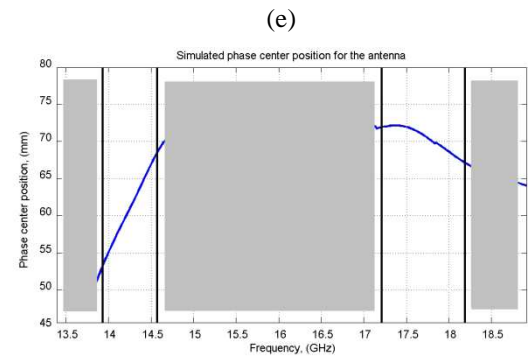
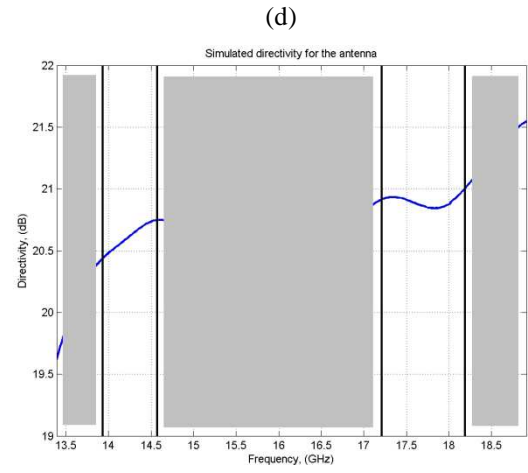
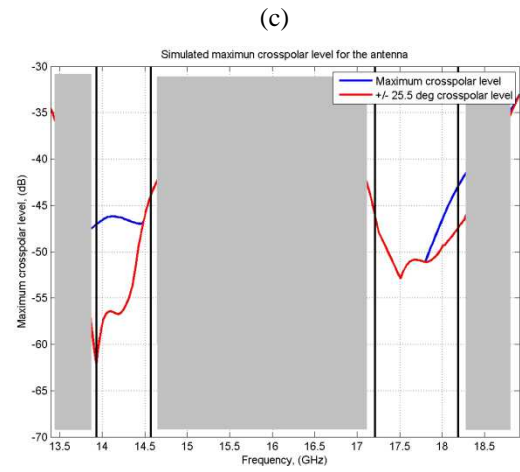
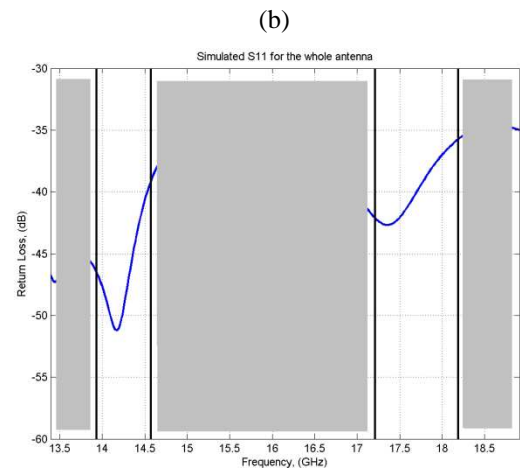
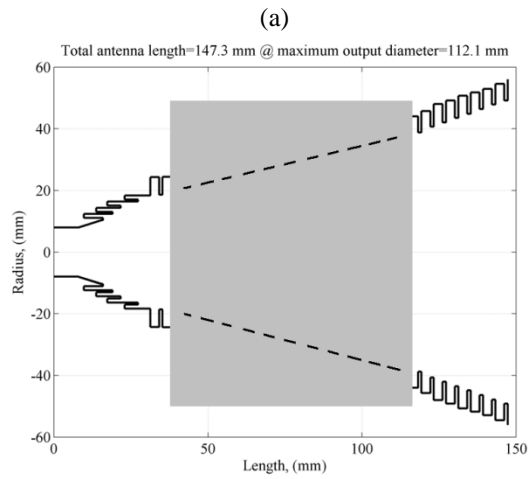


Figure 6.- Ku-Band horn antenna design: the profile (a), the return loss (b), the maximum cross-polarization (c), the directivity (d), the phase centre (e) and the taper illumination at 25.5 degrees (f)

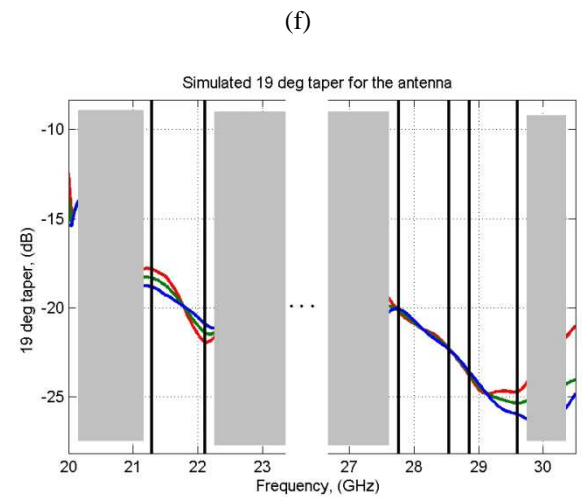
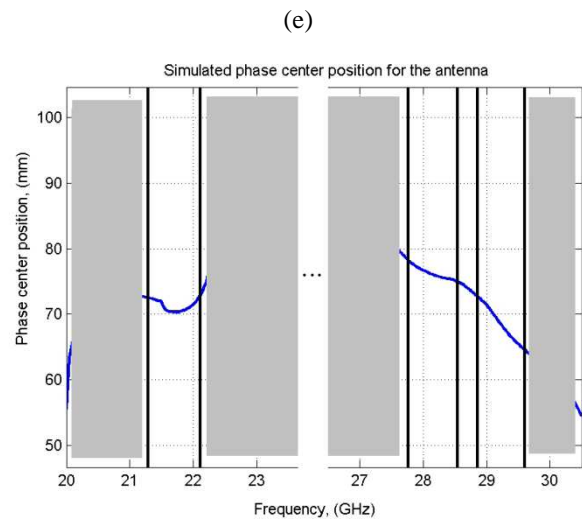
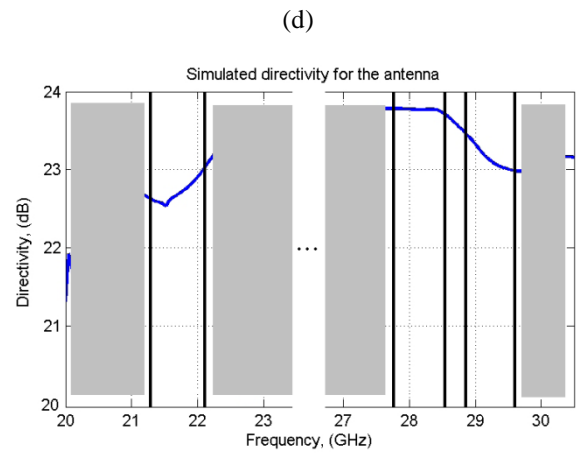
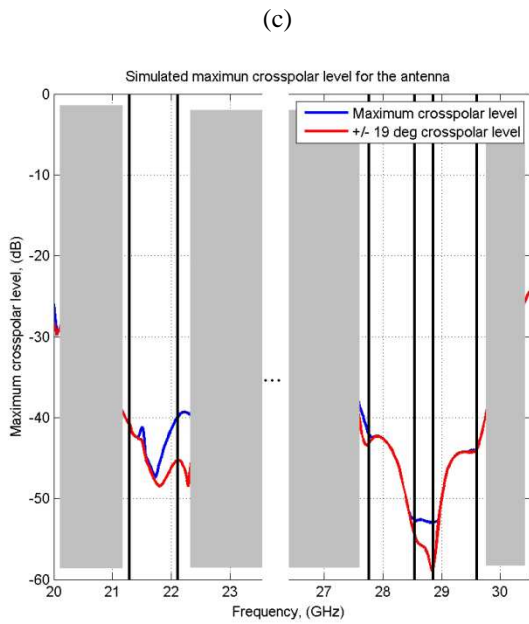
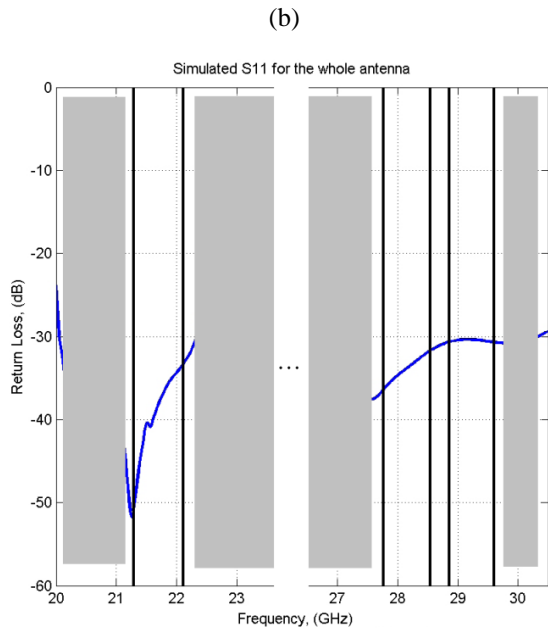
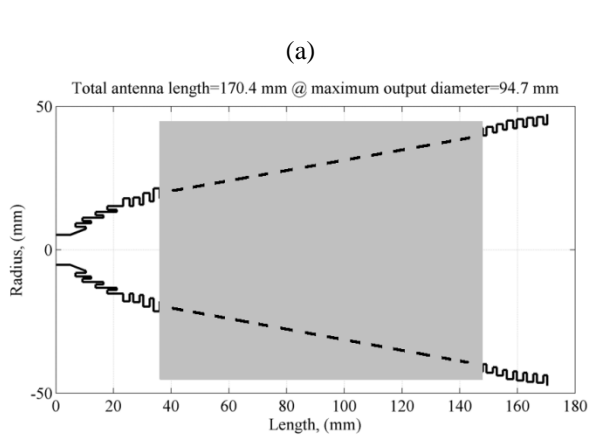


Figure 7.- Ka-band horn antenna design: the profile (a), the return loss (b), the maximum cross-polarization (c), the directivity (d), the phase centre (e) and the taper illumination at 19 degrees (f)

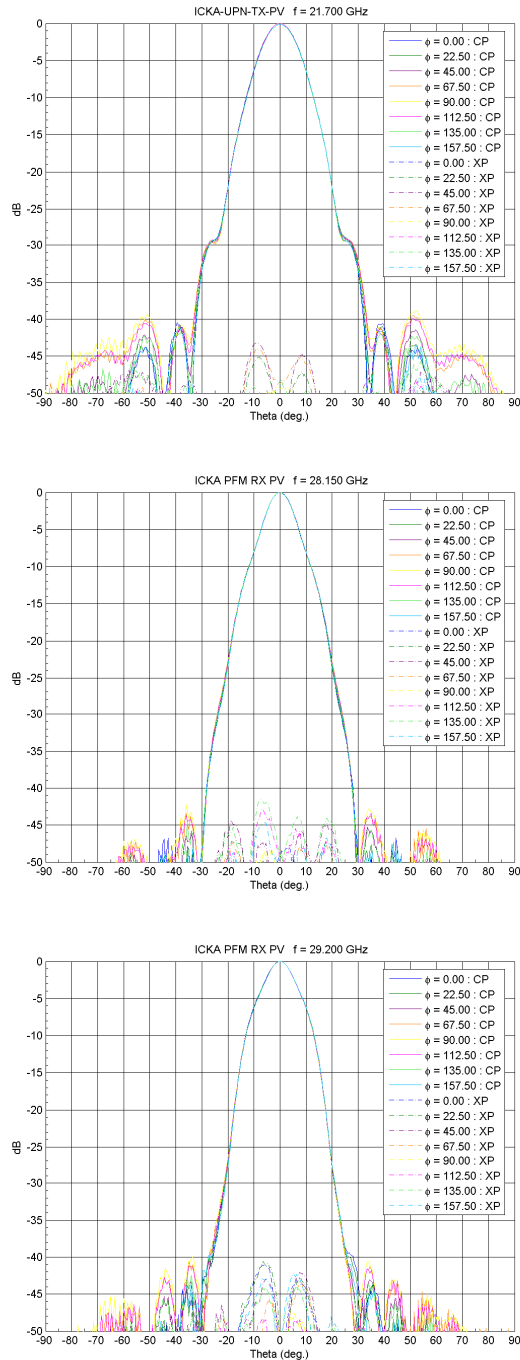


Figure 8.- Measured radiation patterns of IC horn model for ASTRA 3B satellite

6. ACKNOWLEDGEMENTS

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